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A SMALL OXYGEN CONCENTRATOR

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NOTICES

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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Onboard oxygen generating systems (OBOGS) require large quantities of air. When toxic chemical agents are present, this air volume can become a problem. A small oxygen concentr (SOC) was developed to operate at 10% the air volume and 4% the molecular sieve weight OBOGS. This paper gives detailed instructions on the construction of the SOC. The SOC tested at inlet pressures of 10, 20, 30, and 40 psig and at product flows of 0.25, 0.50 and 1.50 lpm. The SOC beds were packed with 5A or 13X molecular sieve. Additional tes were conducted with the SOC beds at 25°C, 50°C, and 60°C and using 5A molecular sieve. SOC performance at various inlet pressures and temperatures, as measured by the oxygen concentration in the product gas, demonstrates characteristics similar to the performance of full-size OBOGS.

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A SMALL OXYGEN CONCENTRATOR

INTRODUCTION

The development and application of aircraft onboard oxygen generating systems (OBOGS) (3, 4) has led to a need to better understand the various parameters of the system. Parameters of particular interest are the ingesti of chemical agents, runway contaminants, and moisture. We need to know if these compounds will be absorbed on the beds and thereby reduce the bed's separation efficiency or will penetrate the beds and appear in the breathing gas.

The current OBOGS, designed for tactical aircraft, uses approximately 30 L of air per minute at 10-40 psig (1 psi = 6.89 kPa). This quantity of air can pose a problem when toxic contaminants are involved, chemical agents in particular. Large quantities of contaminants would be required for the inle at a rate of 300 lpm, and on the exhaust side large quantities of contaminat air would have to be filtered. To circumvent these problems, the Crew Tech-nology Division designed and developed a miniaturized OBOGS, called a SOC (Small Oxygen Concentrator). The SOC was designed to operate at much lower air requirements and with a minimal amount of molecular sieve. Figure 1 sho the assembled unit.

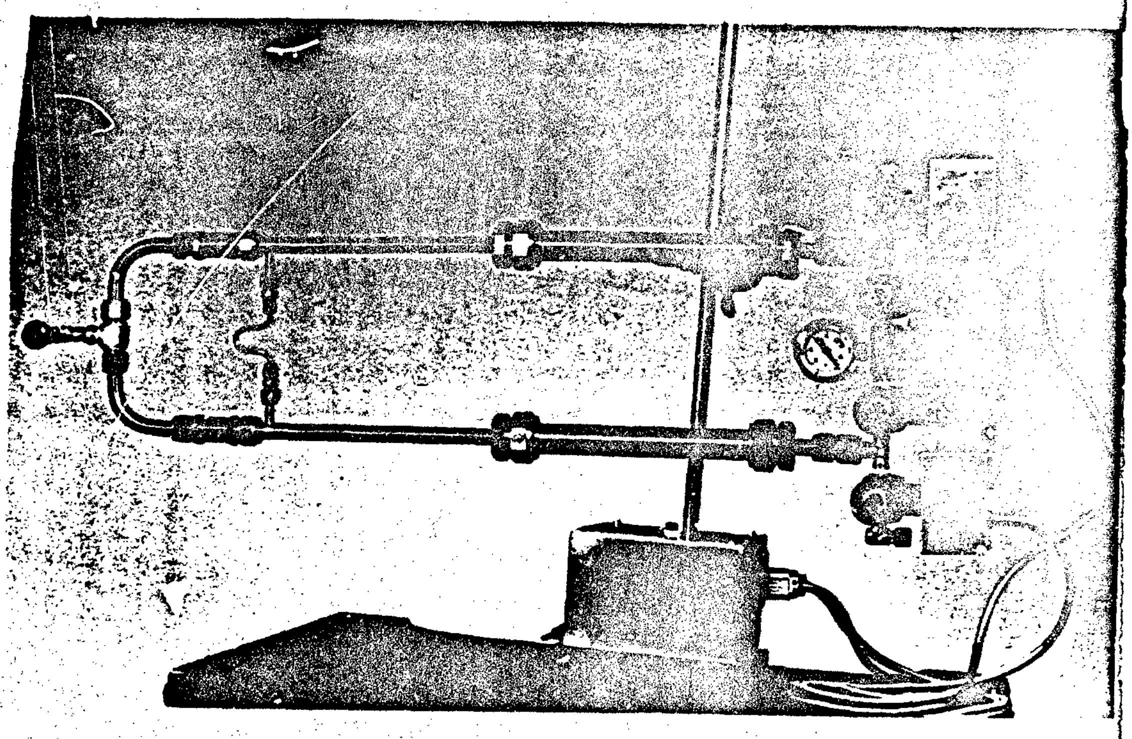

Figure 1. Small oxygen concentrator with solenoid valve programmer.

The SOC has several advantages over the OBOGS when toxic contaminants ar involved. Table 1 shows that the SOC uses only 10% of the air and 4% of the molecular sieve used by the OBOGS. The SOC is constructed with stainless steel (SS) and can be disassembled in a matter of minutes, washed, and decon taminated. When disassembled, the molecular sieve can be sampled at variou places in the bed and the bed repacked with fresh molecular sieve.

TABLE 1. COMPARISON OF OBOGS AND SOC

Parameters	OBOGS	SOC
Air inlet pressure	10-45 psig	10-45 psig
Air used per minute	300 lpm	35 lpm
Molecular sieve (5A/13X)	5,000 g	210 g
Highest percentage of oxygen produced (5A/13X)	94%	94%
Construction	Aluminum	Stainless steel

1 psi = 6.894 kPa

SOC ASSEMBLY

A schematic of the SOC is shown in Figure 2. The components are listed Appendix A.

Beginning with the base fitting (O), assemble the unit as shown in Figur 2. On each side of the fitting, add solenoids (S_2 and S_3); then add tees (I) followed by other solenoids (S_1 and S_4) and then the elbows (J). The soleno ports are labeled "in" and "out." In Figure 2, solenoids S_1 and S_2 would ha "out" on the left and "in" on the right; solenoids S_3 and S_4 would have "out" on the right and "in" on the left. Add the two tube connectors (H) to the t (I). Align this assembly so that the two connectors (H) are parallel to each other and parallel to the solenoids (S_1, S_2, S_3, and S_4). Continue assembly of the SOC toward the product valve (A) until completed.

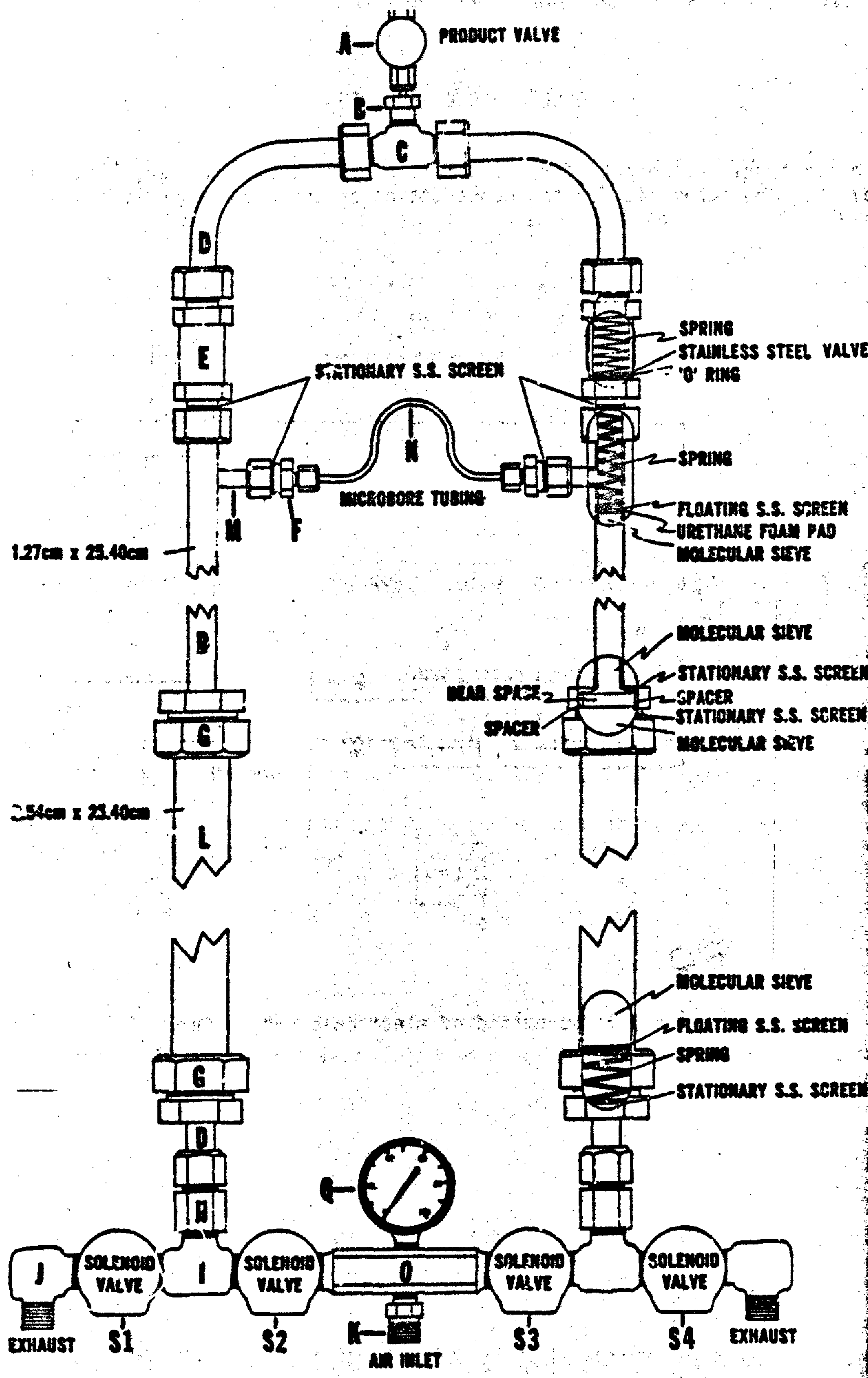

Figure 2. Assembly of small oxygen concentrator.

ELECTRONIC COMPONENTS

The electronic components for the solenoid valve programmer are listed Appendix B. The schematic for the construction of the programmer is shown Figure 3.

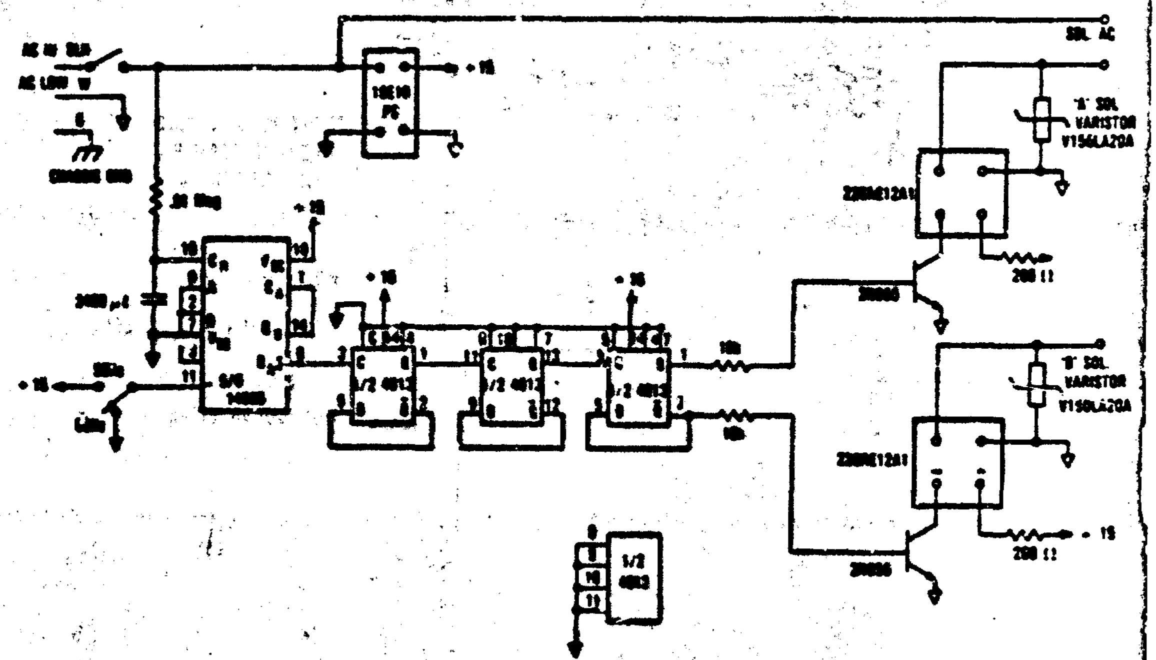

Figure 3. Schematic of electronic programmer.

SOC BEDS PREPARATION

The SOC beds may be packed with either active 5A or 13X molecular sieves. The following procedure is recommended. Loosen the two 1/2" (1.27-cm) Swagelok nuts between the one-way valves and the right-angle 1/2" tubing. Remove the 1/2" tubing with the product valve. Loosen the two 1/4" (0.635-cm) Swagelok nuts on either side of the microbore tubing. Now loosen the two 1/ Swagelok nuts near the solenoid valves and remove beds. Do not loosen or remove the 1" (2.54-cm) Swagelok nut where the 1/2" bed unites with the 1" bed. Remove the 1" nut located at the head end of the bed (nearest to the solenoid valves). Now remove the 1/2" Swagelok nut between the one-way valv and the backflush line. The one-way valve should now be a separate unit. Th 1/2" and 1" beds are now ready to be packed.

When packing the beds always use the "snowstorm" technique (Personal com munication, Dr. Andrew Capon, Chemical Defense Establishment, Porton Down, United Kingdom). (See Appendix C.) Fill the 1" x 10" beds to between 3/8" (0.952 cm) and 1/2" from the top of the tube. Place a SS screen over the mo lecular sieve and place the 7/8" x 1 3/8" (2.222- x 3.492-cm) spring on top the screen. Press the 1" cap, with the 1 3/4" (4.445-cm) length 1/2" tube, down over the spring; tighten nut.

Pack the 1/2" beds to just below the backflush port and place a urethane foam pad over the molecular sieve. With epoxy, glue screen to one end of th 2.5" x 0.42" (6.35- x 1.067-cm) spring. The screen is ground flush with the diameter of the spring. Install this spring with the screen resting against the urethane foam pad and attach the one-way valve over the spring and fitting. Always install the one-way valve with the screen facing the spring.

If the SOC is to be taken apart and reassembled repeatedly, a thread lubricant should be used, particularly on the 1" fitting, to prevent galling. Crawford Fitting Company, Cleveland, OH, manufactures a product (High Purity Goop) for this purpose.

The controller unit is assembled as shown in Figure 3. We recommended that disconnect plugs be installed between the controller unit and the solenoid valves. This allows for easier disassembly and assembly of the SOC. Power required to operate the controller unit and SOC is 120 VAC, 50 or 60 Hz The switch on the controller must be in the appropriate setting (50 or 60 Hz for a properly timed cycle.

The operating sequence of the solenoid valves is as follows: S_1 and S_3 open and S_2 and S_4 closed for 4 s. Then S_2 and S_4 open and S_1 and S_3 closed for 4 s. One complete cycle takes 8 s.

Connect a regulated dry-filtered air of 45-50 psi, with a minimum flow rate of 40 lpm, to a 10-L plenum to inlet fitting (K, Fig. 2). This arrangement will help to smooth out pressure swings as the SOC cycles. Air requirement by the SOC will vary from 12 lpm at 10 psi to 35 lpm at 40 psi.

Check the SOC for leaks before beginning any experimentation. If a leak is indicated, oxygen concentration will be down depending on the size of the leak. To check for leaks, set the inlet pressure up to 40-45 psi, turn the unit on, and carefully go over all the fittings with a leak-detector solution

Other factors that might affect the performance of the SOC are the one valves (E), the microbore tubing (N), and the exhaust ports (J). The one-valves are designed to operate at very low pressures and must close proper If the SOC is not producing the required oxygen concentration and no leaks noted, check these valves to see if a small particle of molecular sieve ha lodged in the valve seat. You can easily check these valves by blowing i them. Air should flow freely in one direction; it should not flow in the opposite direction, not even a slow leak flow. The screen at the inlet si of the one-way valve should protect the valve from molecular sieve particl

Place a screen on each end of the microbore tube in the 1/4" side of t Swagelok fitting. This also should prevent the microbore tube from becomi clogged or plugged with molecular sieve particles.

The two exhaust ports (J) located on the outboard side of the two oute solenoid valves can be attached to a common plenum, individual plenums, or exhaust to the atmosphere. However, do not restrict the flow of these exh lines since restriction will reduce the performance of the SOC.

RESULTS AND DISCUSSION

The SOC was tested with 5A, medical grade (MG), 16-40 mesh, molecular sieve, and 13X, 16-40 mesh, molecular sieve (1). Good oxygen/nitrogen sepa tion was obtained by using activated molecular sieve. The SOC beds were s storm packed with either 5A or 13X molecular sieve and tested at inlet pressures of 10, 20, 30, and 40 psig. The product flow was set at 0.25, 0.5 1.00, and 1.50 lpm using a rotameter. The product gas was analyzed (with a Perkin-Elmer MGA-1100 medical gas analyzer) for oxygen, nitrogen, and argon Tables 2 and 3 show the results. At high product flows $\geq$1 lpm, the average concentration was recorded. All tests, unless otherwise stated, were deter mined at ambient temperature.

If the product flow is maintained at a constant flow and the inlet pres sure is increased, the oxygen content will increase to a maximum level. If inlet pressure is increased to a still higher level, the oxygen concentrati will start to decrease. This decrease is caused by the increased flow rate through the beds while the cycle time of the solenoid valves remains the sa Increasing the oxygen content at high inlet pressure would require larger b and/or a change in the cycle time. Table 2 and Figure 4 indicate that an inlet pressure of 20 or 30 psig is the best for 5A with an 8-s cycle time.

If the inlet pressure is maintained at a constant pressure and the prod flow is increased, the oxygen concentration will decrease. Table 2 and Figu 5 illustrate these results.

TABLE 2. PRODUCTS OF SOC PACKED WITH 5A MOLECULAR SIEVE

	Product (lpm)	Oxygen (%)	Nitrogen (%)	Argon (%)
Inlet pressure 10 psig				
	0.25	92.7	2.3	5.0
	0.50	82.7	13.2	4.0
	1.00	50.6	46.7	2.4
	1.50	40.0	58.3	1.9
Inlet pressure 20 psig				
	0.25	94.0	0.7	5.3
	0.50	93.8	1.3	4.9
	1.00	90.2	5.5	4.3
	1.50	76.3	20.0	3.6
Inlet pressure 30 psig				
	0.25	93.9	1.3	4.8
	0.50	93.5	1.9	4.6
	1.00	91.5	4.1	4.3
	1.50	86.6	9.4	4.0
Inlet pressure 40 psig				
	0.25	92.5	3.1	4.3
	0.50	91.9	3.6	4.2
	1.00	88.9	7.0	4.0
	1.50	85.0	11.1	3.8

1 psi = 6.894 kPa

TABLE 3. PRODUCTS OF SOC PACKED WITH 13X MOLECULAR SIEVE

	Product (lpm)	Oxygen (%)	Nitrogen (%)	Argon (%)
Inlet pressure 10 psig				
	0.25	92.8	2.4	4.6
	0.50	80.3	16.0	3.8
	1.00	51.8	45.4	2.4
	1.50	42.4	55.5	2.0
Inlet pressure 20 psig				
	0.25	93.2	1.8	4.5
	0.50	91.1	4.5	4.3
	1.00	81.1	14.9	3.8
	1.50	67.2	29.5	3.1
Inlet pressure 30 psig	0.25	90.8	4.8	4.2
	0.50	88.5	7.2	4.0
	1.00	81.9	14.1	3.7
	1.50	73.5	23.1	3.3
Inlet pressure 40 psig	0.25	83.8	12.2	3.7
	0.50	81.7	14.6	3.6
	1.00	76.2	20.0	3.4
	1.50	69.9	27.2	3.1

1 psi = 6.894 kPa

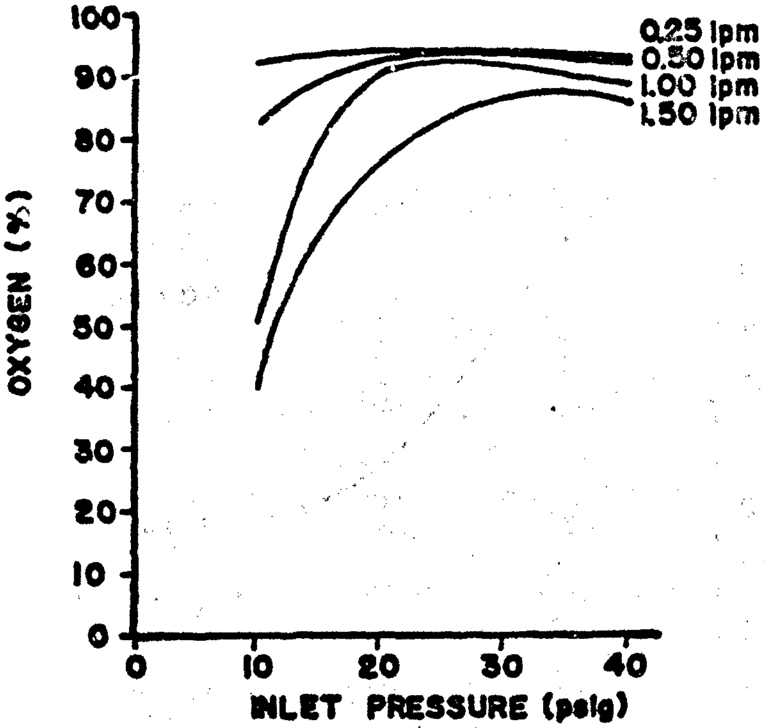

Figure 4. Precentage of oxygen versus inlet pressure when using SOC with 5A molecular sieve.

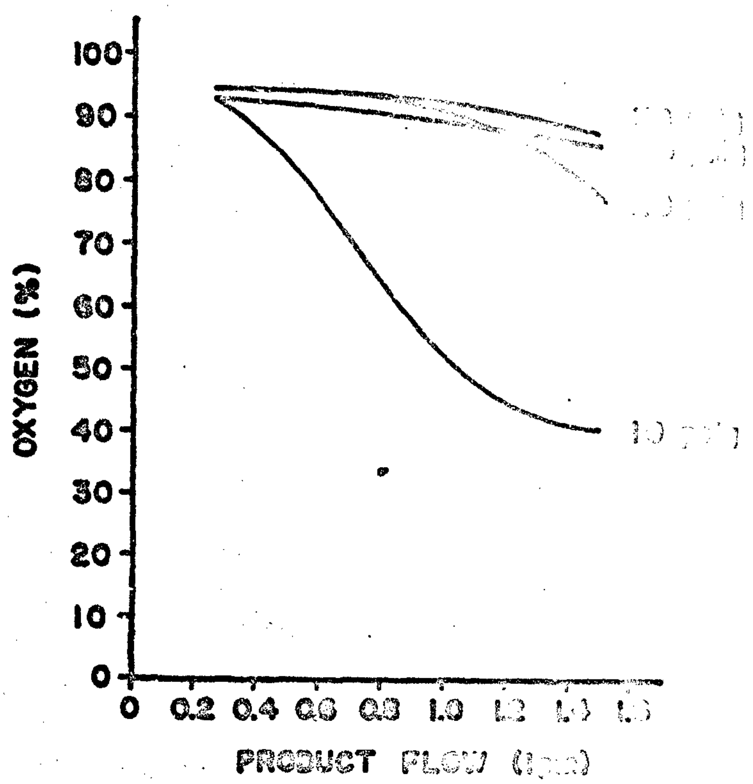

Figure 5. Percentage of oxygen versus product flow rate when using SOC with 5A molecular sieve; constant inlet pressure and increased product flow.

The SOC packed with 5A molecular sieve was also tested at temperatures of [illegible]°C, 50°C, and 60°C. Heat for the four SOC beds was provided by four clamshell heaters. Temperature was monitored in the clam shells and controlled by the Variacs. The inlet gas was not preheated. An increase in temperature caused a decrease in the oxygen concentration. The results are shown in Figure 6.

The SOC was repacked with 13X molecular sieve and tested at the same inlet and product flows as the 5A molecular sieve. The results are shown in Table 3 and Figures 7 and 8. Although the results are similar to those with the 5A sieve, the higher oxygen concentrations could not be achieved.

The testing of the SUC proved that it has the same characteristics as the OBOGS (2). The OBOGS and SOC have similar inlet-pressure and product-flow variations. Both units become less effective with heat, and both give better oxygen concentrations with 5A than with 13X molecular sieve. At low product flows both give good high oxygen concentrations. The one maj.r difference is that when compared with the OBOGS, the SOC uses a fractional amount of molecular sieve and air. This makes it ideal for testing of dangerous contaminants.

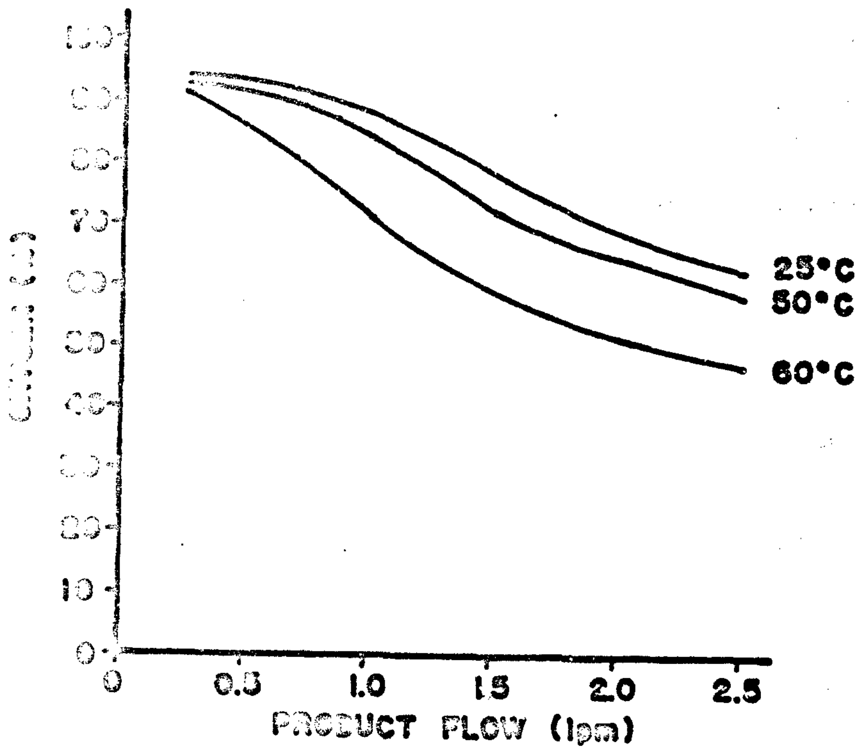

Figure 6. Percentage of oxygen versus product flow rate when using SOC with 5A molecular sieve; bed temperature at 25°C, 50°C, and 60°C, with inlet pressure of 30 psig.

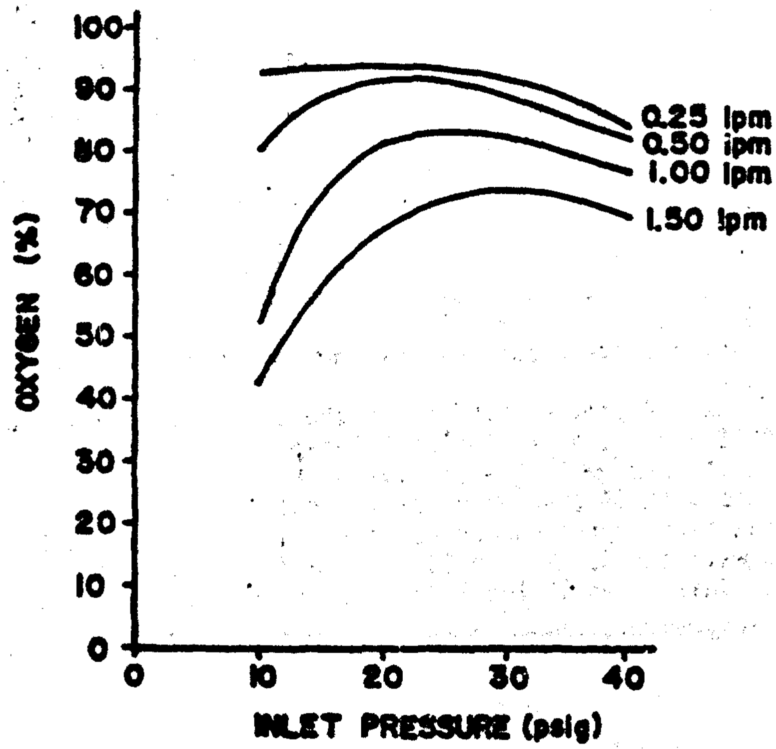

Figure 7. Percentage of oxygen versus inlet pressure when using SOC with 13X molecular sieve.

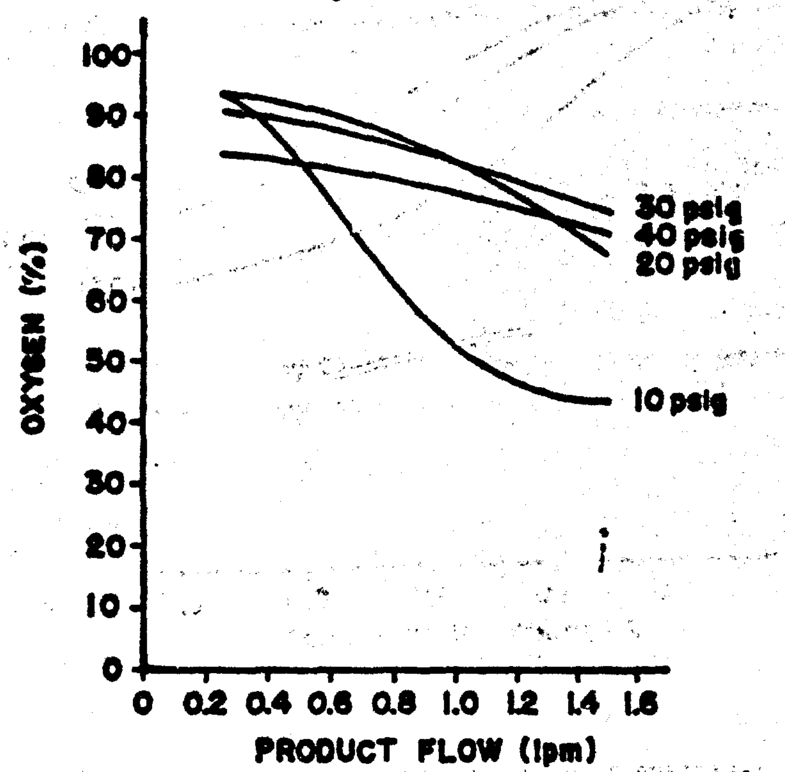

Figure 8. Percentage of oxygen versus product flow rate when using SOC with 13X molecular sieve.

With minor changes the SOC can also be used to demonstrate an inert-gas concentrating system. These include packing the beds with 4A (14 x 30 mesh) molecular sieve and reducing the cycle time to 2 s or less. The sequence of the solenoids--S_1, S_2, S_3, and S_4--remains as previously described with the exception of the timing. The timer used in this demonstration to drive the solenoids was a variable-time programmer similar to the one depicted in Figure 3.

The SOC packed with 4A molecular sieve, and with a 2-s cycle and an inlet pressure of 20 psig, delivered a product gas consisting of 92.9% N_2 at 0.25 lpm, 92.5% at 0.50 lpm, 91.6% at 1.00 lpm, and 90.6% at 1.50 lpm; in all cases the argon remained fairly constant at 1.2%.

As noted above, the variation of the product flow (and inlet pressure) does not affect the inert-gas production to the extent as when the SOC is used for oxygen production (Table 2).

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3. Skarstrom, Charles W. Recent developments in separation sciences, Vol II, pp. 95-106. CRC Press, Cleveland, OH, 1972.

4. Skarstrom, Charles W. Use of adsorption phenomena in automatic plant-type gas analyzers. Ann NY Acad Sci, 72 Art. (13):751-763, 1959.

APPENDIX A. SOC COMPONENTS

Item	Qty	Description
A*	1	Shutoff valve with 1/8" Swagelok connections, SS, Whitey, SS-ORS2
B*	1	Male adapter, tube to pipe, 1/8" O.D. - 1/4" male pipe, SS, Cajon, SS-2-TA-1-4RT
C*	1	Union tee, 1/2", SS, Swagelok, SS-810-3
D*	∿ 40" (1 m)	Tubing, SS 304, size 0.50" O.D. X 0.028" wall, FSN 4710-00-278-8069
E*	2	Check valve, 1/2" Swagelok connector on both ends, cracking pressure is 1/3 lb, SS, Nupro, SS-8C-1/3
F*	2	Reducing union, 1/4" to 1/8" Swagelok connections, SS, Swagelok, SS-400-6-2
G*	4	Cap, 1" tube O.D., SS, Swagelok, SS-1610-C
H*	2	Connector, tube to female NPT, 1/2" tube to 1/4" P-NPT, SS, Swagelok, SS-810-7-4
I*	2	Male tee, 1/4" P-NPT, SS, Cajon, SS-4-MT
J*	2	Male elbow, 1/4" tube to 1/4" P-NPT, SS, Swagelok, SS-400-2-4
K*	1	Male connector, 1/4" tube to 1/8" P-NPT, SS, Swagelok, SS-400-1-2
L*	20" (.5 m)	Tube, SS 304, Mil-T-8506A, 1" O.D. x 0.028" wall, FSN 4710-00-585-8977
M*	∿ 4" (10 cm)	Tubing, SS 304, 0.25" O.D. x 0.035" wall FSN 470-00-278-8096
N*	∿ 8" (20 cm)	Microbore tubing, SS, 0.125" O.D. x 0.028" I.D.
O*	1	Hexagon, SS 303, 0.625" O.D., FSN 9510-00-293-4962
Q*	1	Pressure gauge, series 23K (1/8" NPT) range 60 psi, 2" diameter, Cat. #G14421, Marshalltown Instruments, P.O. Box 400, 710 S 12th Ave., Marshalltown, IA 50158

*Location on Figure 2 in text.

Item	Qty	Description
S*	4	Solenoid valve, M.O.P.D. 40, 11 watts, 120 volts, 60 Hz, 1/4" orifice, Airmatic-Allied Inc. Cat. #20317, Airmatic Allied Inc., Wilmington, OH 45177.
(Below E*)	2	Spring, compression, ground ends, SS, Lee Cat. #1-8, p. Lee stock #LC-045F-11, size 2.50" x 0.420". Lee Spring Co., 30 Main St., Brooklyn, NY 11201.
(Under lower G*)	2	Spring, compression, SS. Associated Spring Cat., p. 37. Cat. #S-C0850-081-1250, size 1.25" x 0.85". Associated Spring, Barnes Group Inc., P.O. Box 210095, Dallas, TX 75211.
4**	2	O-ring seal, neoprene, Nom, 11/16" O.D. x 9/16" I.D. x 1/16" W., Parker Seal Company, Culver City, CA, and Cleveland, OH.
6**	2	O-ring seal, neoprene, Nom, 5/8" O.D. x 7/16" I.D. x 3/32" W., Parker Seal Company, Culver City, CA, and Cleveland, OH
Figure 2		Stainless-steel screen: wire cloth, SS, twilled weave, mesh, wire size 0.011", 1 over, 2 under. F. P. Smith Wire Cloth Co., 10112 Pacific Ave., Franklin Park, IL 60131
4**		Tube, SS, 0.535" O.D. and 0.50" I.D.
(Under upper G*)		Tube, SS, 7/8" O.D. and 3/4" I.D.
E* and 5**		Sheet, SS, 0.01" thick
E* and 5**		Sheet, rubber, 0.03" thick
Molecular sieve, type 5A MG, size 16 x 40, Union Carbide		
Molecular sieve, type 13X, size 16 x 40, Union Carbide		

Note: Items with no company address stated were purchased locally.
*Location on Figure 2 in text.
**Location on Figure A-1.

Several of the listed items must be modified to some extent by a component machinist. These include

C -- This 1/2" union tee requires the threads to be cut off the center connector and tapped with a 1/4" NPT tap.

E -- These two check valves need to be modified as shown in Figure A-1. Disassemble the check valve and remove the plunger and spring. Discard the plunger; the spring will be reused. Mill a SS sleeve to 0.535" O.D. and 0.50" I.D. and press fit into the housing. This SS sleeve is

used as a spring guide. The exposed end of the sleeve has four half-moon cuts in it to allow for air passage. Punch a 5/8" disk from a sheet of 0.010" SS. Glue this disk (it must be flat) with epoxy to one end of the spring that was removed earlier. Cut a 5/8" disk from 0.030" sheet rubber and glue it, with Pliobond, to the top of the SS disk that was glued to the SS spring. Glue an O-ring to the body of the valve to serve as a seat for the disk to strike. A good seal is required to prevent the air from passing between the O-ring and the housing. Place another O-ring behind the threads where the two portions of the valve-housing screw together. Before locking the tube and ferrules in place, punch out a 1/2" disk of wire cloth (Fig. A-1, No. 8) and place on the inlet side of the valve.

G -- Drill a 1/2" hole in the center of each of the four 1" caps. The inside of two of the caps is milled flat to a diameter of 7/8". Place one end of a 10" length of 1/2" SS tube in each of the milled caps with the end flush with the inside of the cap, and silver solder in position. The milled space will be used as a dead space. In the 1/2" hole of the other two 1" caps, place 1 3/4" lengths of 1/2" SS tube. Silver solder the two tubes in so that one end of the tube is flush with the inside of the cup.

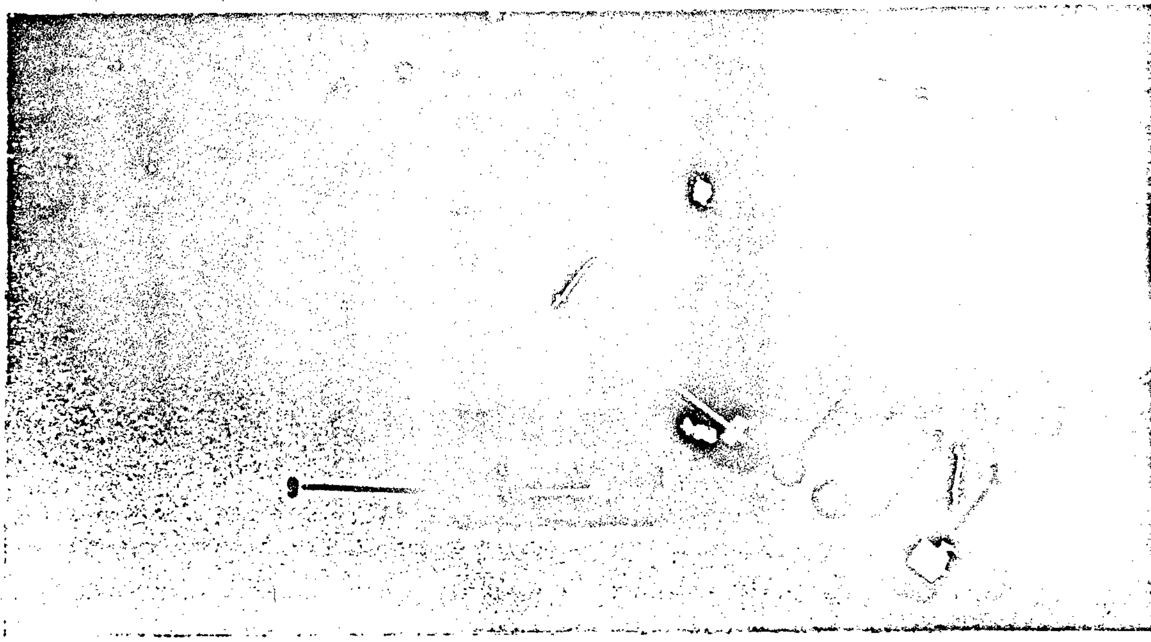

Figure A-1. One-way valve.

1. 1/2" nut
2. Back ferrule
3. Front ferrule
4. Valve housing with spring guide and O-ring
5. Spring with SS and rubber disk
6. O-ring
7. Valve housing
8. SS screen
9. Assembled one-way valve

O -- Cut a hexagonal SS Bar to a 3" length and bore out the length of the bar to a diameter of 1/4". Mill both ends and thread with a 1/4" NPT die. Drill two holes in the center of the bar on opposite sides and tap with a 1/8" NPT tap.

The following items require construction from basic materials.

G -- The two 10" x 1/2" SS tubes with the 1" cap will need further modific tion. Drill a 1/4" hole 1 1/4" from the end of the 1/2" x 10" SS tubes; cut a 1 3/8" length of 1/4"-O.D. SS tubing and place in the drilled hole at a 90° angle. The 1/4" tube should not protrude into the 1/2" tube, but be flush mounted with the inside. This is necessa to allow the spring in the 1/2" tube to slide freely past the 1/4" tu opening. We recommend that the silver solder joint be built up to strengthen the connection and prevent minute leaks.

G -- Swagelok 1" cap with 1/2" x 10" and 1" x 10" SS tubes. A small space (plenum) is required between the 1/2" x 10" and the 1" x 10" SS tubes to duplicate a similar space in the full-size concentrator beds. To provide this space, punch a 7/8" SS screen out of wire cloth and plac it in the milled portion of the 1" cap. Make a spacer by cutting a 1/8" length of a 7/8"-O.D., 3/4"-I.D. SS tube, and place this spacer top of the 7/8" SS screen. Next place a 1"-diameter SS screen over t spacer. In this fitting, place the 1" SS tube with ferrules and lock it in place. The 1" and 1/2" beds are now attached, with the small plenum in between.

D -- Bend a length of 1/2" SS tube at right angle with a tube bender and c to a proper length to fit between the valve E and the tee C.

N -- Cut the microbore tubing to a length of 5", making sure that the hole in the end are not crimped or obstructed. Bend the 5" length to the shape shown in Figure 2 in the text.

APPENDIX B. ELECTRONIC COMPONENTS FOR SOLENOID VALVE PROGRAMMER (4-SECOND TIM

Item	Mfg	P/N	Qty
Integrated circuit	Motorola	MC14566	1
Integrated circuit	Motorola	MC14013	2
Transistor	Motorola	2N956	2
Varistor	G.E.	V150LA20A	2
SS relay	Sigma	226RE1-12A1	2
Resistor, 200 ohm 1/4 watt, 5%	Allen-Bradley	RC07GF201J	2
Resistor, 10 kohm 1/4 watt, 5%	Allen-Bradley	RC07GF103J	2
Resistor, 0.91 Mohm 1/4 watt, 5%	Allen-Bradley	RC07GF914J	2
Switch, SPDT	Alcoswitch	TT13D-2T	1
Switch, SPST	Alcoswitch	TT13A-2T	1
Cabinet	Bud Radio Inc.	AU1029LG	1
Capacitor	Mallory	CK06BX222K	1
Receptacle, duplex	Hubbell	5242	1
Power cord	Belden	17512C	1

APPENDIX C. SNOWSTORM PACKING

The snowstorm packing technique uses a series of screens (Fig. C-1) to delay and disperse the fall of the particle. This allows each particle to fall and lie in its lowest energy state, without tenting.

To pack the 1" bed, use a 1"-O.D. x 3/4"-I.D. x 10.5"-L tube, in combination with a funnel, with three wire cloths placed in the appropriate positions (see Figs. C-1 and C-2). The wire cloth specifications are 8 x 8 mesh per linear inch, 0.032" wire diameter, with 0.093" opening and 55.4% open area. The wire cloth can be purchased from McMaster-Carr Supply Co., P.O. Box 4355, Chicago, IL 60680; stock #9226W30.

To pack the 1/2" bed, use a 5/8"-O.D. x 1/2"-I.D. tube, in combination with a funnel, with wires installed at 60° angles to each other at each of the three appropriate positions (Figs. C-1 and C-2). The cross wires can be formed from 20-gauge wire.

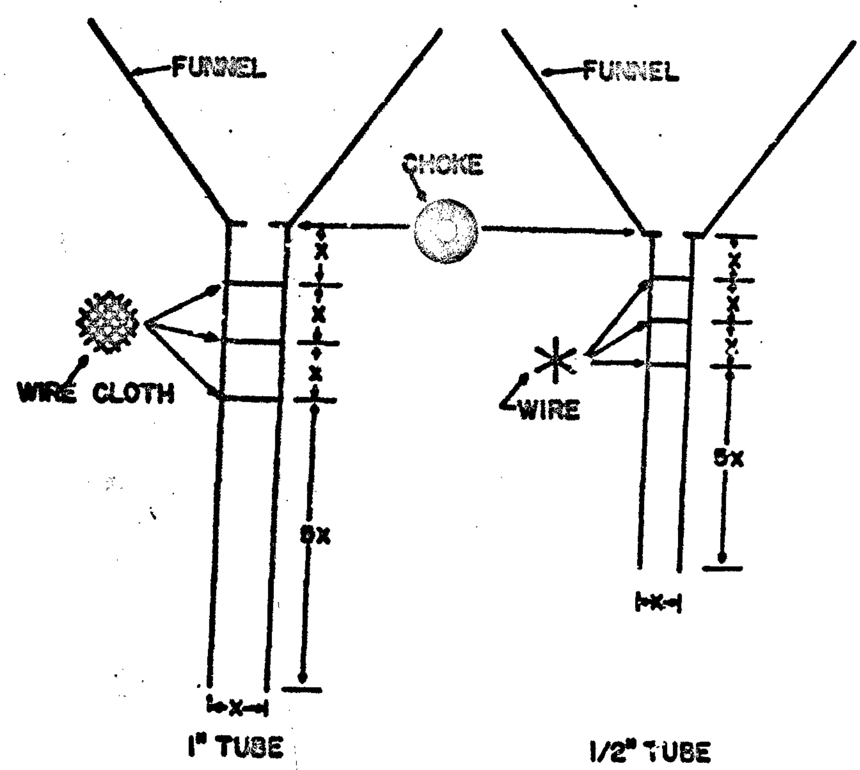

Figure C-1. Diagram of snowstorm-packing apparatus. Tube diameter (x) is equivalent to the bed to be filled.

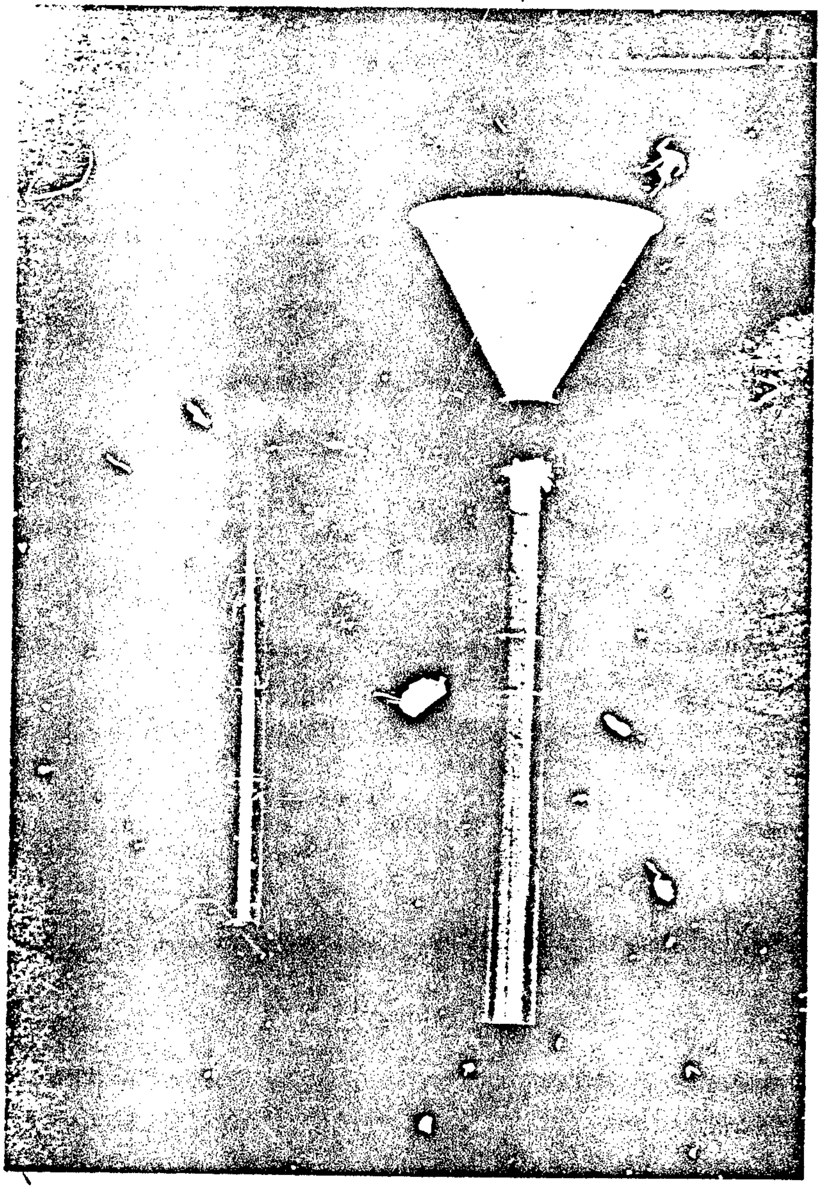

Figure C-2. Apparatus for snowstrom packing SOC beds.
Left: for packing 1/2" bed
Right: for packing 1" bed